Method and Apparatus for Runout Correction During Self-Servo Writing

By

Thomas Melrose

and

James Hargarten

Related Application

Priority is claimed from U.S. Provisional Patent Application Serial No. 60/403,583, entitled "ON THE FLY SSW ERC", filed on August 14, 2002, which is incorporated herein by reference in its entirety.

Field of the Invention

The present invention relates to self-servo writing disk drives and, more particularly, to runout correction while self-servo writing disk drives.

Background of the Invention

Background for the present invention is provided herein in connection with a disk drive system. It should be noted, however, that the present invention is not intended to be limited to such systems.

A disk drive is a data storage device that stores digital data in tracks on the surface of a data storage disk. Data is read from, or written to, a track of the disk using a transducer that is held close to the track while the disk spins about its center at a substantially constant angular velocity. To properly locate the transducer near the desired track during a read or write operation, a closed-loop servo scheme is generally implemented that uses servo data read from the disk surface to align the transducer with the desired track.

The servo data includes servo patterns that typically comprise short servo bursts of a constant frequency signal, which are very precisely located and are offset from either side of a data track's centerline. The bursts are written in a sector header area, and can be used to find the centerline of a track. Staying on-center is required during both reading and writing. These servo-data areas allow a head to follow a track centerline around a disk, even when the track is out-of-round, as can occur with spindle wobble, disk slip and/or thermal expansion.

Servo bursts are conventionally written on a disk in the disk drive by a dedicated, external servo track writer (STW),

which typically involves the use of large granite blocks to support the disk drive and quiet outside vibration effects. Unfortunately, servo track writers are expensive, and require a clean room environment, as the disk and heads are exposed to the environment to allow the access of the servo track writer's external head and actuator. Accordingly, self-servo writing (SSW) methods for writing a servo-pattern with a disk drive's own transducers have been utilized.

Typically in a SSW process, a temporary set of pre-existing reference servo information on a disk is used to control the transducer position while the final servo bursts are written to disk(s) in the disk drive. The SSW process involves a combination of three largely distinct sub-processes, including: reading the temporary servo information to provide precise timing, positioning a transducer at a sequence of radial positions using the variation in a read back signal amplitude as a sensitive position indicator, and writing the final servo burst patterns at the times and radial positions defined by the other two processes, to form concentric circular tracks. An example SSW process is described in U.S. Patent No. 5,907,447 to Yarmchuk, et al. Other SSW processes are possible, such as servo propagation where the servo reader-to-writer offset is used to allow

servoing on one set of servo bursts while writing another servo burst.

In an ideal disk drive system, the tracks of the data disk are non-perturbed circles that are situated about the center of the disk. As such, each of these ideal tracks includes a track centerline that is located at a known constant radius from the disk center. In an actual system, however, it is difficult to write non-perturbed circular tracks to the data storage disk. That is, problems, such as vibration, bearing defects, etc. can result in tracks that are written differently from the ideal non-perturbed circular track shape. Positioning errors created by the perturbed nature of these tracks are known as written-in repetitive runout (SSW_RRO). The perturbed shape of these tracks complicates the transducer positioning function during read and write operations performed after the SSW process, because the servo system needs to continuously reposition the transducer during track following to keep up with the constantly changing radius of the track centerline with respect to the center of the spinning disk. Furthermore, the perturbed shape of these tracks can result in problems such as track squeeze and track misregistration errors during read and write operations.

In certain systems, as will be understood by those skilled in the art, after all the servo patterns for all tracks are written, an additional process is used to directly measure the SSW_RRO for each track of a disk so that compensation values are generated and written in servo fields on the disk. Thereafter, during read/write operations, the compensation values are used to position the transducer along an ideal track centerline. An example of such a process is described in U.S. Patent No. 6,549,362 to Melrose, et al. ('362 patent), incorporated herein by reference.

Although, such a correction technique is effective, it can be time consuming. After the SSW process is completed, the amount of SSW_RRO present on each track of a disk must be measured, and then a calculation is performed to determine correction factors to minimize the SSW_RRO in each track. Finally, the correction factors must be written to the disk in each servo field of each track. This process requires several revolutions to measure the SSW_RRO and then more revolutions to write the correction factors to the disk. In one example, such a process may require 12 or more revolutions to determine, and write, correction factors for each track.

There is, therefore, a need for a more efficient method and apparatus for improving embedded runout correction in a disk drive during the self-servo writing process, while reducing the correction time required.

Brief Summary of the Invention

The present invention addresses the above needs. In one embodiment, the present invention provides a method and system for self-writing track locations of a storage surface of a data disk of a disk drive, wherein the runout in the write tracks is determined during the self-servo writing (SSW) process. Runout correction values are calculated and then (immediately) written into corresponding RRO fields in the write position during the SSW process.

An example of such a self-servo writing method according to the present invention includes the steps of: self-writing first servo bursts along a circular track via a transducer and determining a first position error signal indicating repeatable runout due to mis-positioning of said first servo bursts, calculating a runout correction value based on the first position error signal, and storing the runout correction value for the first servo bursts in a

corresponding servo sector while self-writing track locations.

In one implementation, self-writing servo bursts further includes the steps of self-writing second servo bursts along the track via the transducer, and determining a second position error signal indicating repeatable runout due to mis-positioning of said second servo bursts, wherein the first and second servo bursts form servo sector patterns that define the track centerline. Then, the runout correction value is calculated based on the first and second position error signals, and stored in a corresponding servo sector while self-writing track locations.

In one example, each servo sector pattern includes a trimmed burst pattern, wherein self-writing said first servo bursts in each servo sector pattern further includes the steps of writing two servo bursts such that one of the servo bursts trims the other servo burst, defining a first seam. In that case, the first position error signal indicates repeatable runout due to mis-positioning of the first seam. Further, self-writing said second servo bursts in each servo sector pattern further includes the steps of writing two servo bursts such that one of the servo bursts trims the

other servo burst, defining a second seam. In that case, the second position error signal indicates repeatable runout due to mis-positioning of the second seam. For example, each servo sector pattern can include a trimmed burst pattern comprising four radially offset, circumferentially staggered, servo bursts. Alternatively, each servo sector pattern can include an un-trimmed burst pattern.

In another embodiment, determining the first position error signal further includes the step of determining a first instantaneous position error signal indicating said repeatable runout while self-writing the first servo bursts. Further, determining the second position error signal includes the step of determining a second instantaneous position error signal indicating said repeatable runout while self-writing the second servo bursts. One implementation involves recording the first and second instantaneous position error signals obtained while self-writing the first servo bursts, and then calculating the runout correction value using the recorded first and second instantaneous position error signals.

Further, the data disk can include a reference pattern which provides position information for self-writing the

servo bursts, such that the first and second position error signals are generated based on the position information from the reference pattern.

In another aspect, the present invention provides a disk drive including a controller which implements the self-servo writing method of the present invention.

Other objects, features, embodiments and advantages of the invention will be apparent from the following specification taken in conjunction with the following drawings.

Brief Description of the Drawings

FIG. 1 is a diagrammatic representation of a top view of a hard disk drive, with the cover removed;

FIG. 2 is a diagrammatic representation of a magnetic storage disk having a data track that is compensated for runout in accordance with the present invention;

FIG. 3 is a diagrammatic representation of a servo burst pattern that may be used to position a transducer head with respect to a track centerline;

FIG. 4 is a flowchart of the steps of an example self-servo writing (SSW) process according to an embodiment of the present invention;

FIG. 5A is a diagrammatic representation of a servo burst pattern written according to the self-servo writing steps in FIG. 4; and,

FIG. 5B is another diagrammatic representation of a servo burst pattern written according to the self-servo writing steps in FIG. 4.

Detailed Description of the Invention

While this invention is susceptible of embodiments in many different forms, there are shown in the drawings and will herein be described in detail, preferred embodiments of the invention with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the broad aspects of the invention to the embodiments illustrated.

Further, although in the description below, example embodiment of the present invention are described in connection with a disk drive system, it should be noted,

however, that the present invention is not intended to be limited to such systems.

FIG. 1 illustrates a typical computer disk drive. The disk drive, generally identified by reference number 100, includes a base 104 and magnetic disks 108 (only one of which is shown in FIG. 1). The magnetic disks 108 are interconnected to the base 104 by a spindle motor (not shown) mounted within or beneath the hub 112, such that the disks 108 can be rotated relative to the base 104. Actuator arm assemblies 116 (only one of which is shown in FIG. 1) are interconnected to the base 104 by a bearing 120. The actuator arm assemblies 116 each include a transducer head 124 at a first end, to address each of the surfaces of the magnetic disks 108. A voice coil motor (VCM) 128 pivots the actuator arm assemblies 116 about the bearing 120 to radially position the transducer heads 124 with respect to the magnetic disks 108. By changing the radial position of the transducer heads 124 with respect to the magnetic disks 108, the transducer heads 124 can access different data tracks or cylinders 132 on the magnetic disks 108. The voice coil motor 128 is operated by a controller 136 that is in turn operatively connected to a host computer (not shown). A

channel 140 processes information read from the magnetic disks 108 by the transducer heads 124.

As illustrated in FIG. 2, the disk 108 is substantially circular in shape and includes a center point 200 located in the center of the disk 108. The disk 108 also includes a plurality of tracks 132 (only one of which is illustrated in FIG. 2) on an upper surface 204 of the disk 108 for storing the digital data. The data tracks 132 are divided into data fields 208a-208d and servo sectors or hard sectors 212a-212d. Generally, the data fields 208a-208d are used for storing data as a series of magnetic transitions, while the servo sectors 212a-212d are used for storing servo information, also as a series of magnetic transitions/bursts, that is used to provide the transducer head 124 with positioning information. In particular, the servo sectors 212a-212d provide the transducer heads 124 with information concerning their position over the magnetic disk 108. More particularly, the servo sectors 212a-212d provide information to the transducer heads 124 concerning the identity of the track 132 and servo sector 212 over which each transducer head 124 is flying, and concerning the position of each transducer head with respect to the centerline of the track 132.

Although the magnetic disk 108 illustrated in FIG. 2 is illustrated as having a relatively small number of data tracks 132 and servo sectors 212, it can be appreciated that a typical computer disk drive contains a very large number of data tracks 132 and servo sectors 212. For example, computer disk drives having over 100,000 tracks per inch and 240 sectors are presently available.

The disk drive 100 includes a servo control system 144 for controlling the position of a transducer head 124 with respect to a track 132 being followed. In general, the servo control system comprises the transducer head 124 being positioned, which reads the position information from the servo sectors 212; the actuator arm assembly 116 that is carrying the transducer head 124; the voice coil motor 128; the channel 140; and the controller 136. As described in the '362 patent, the response of the servo control system 144 to a given input is given by the error transfer function of the servo control system 144.

The track 132 is ideally non-perturbed and ideally shares a common center 200 with the disk 108, such as ideal track 216 illustrated in FIG. 2. Due to system imperfections, however, the actual written track 132 can be

perturbed as compared to an ideal track 216 such as non-ideal track 132 as illustrated in FIG. 2. A perturbed or non-ideal track 132 is difficult for a transducer head 124 to follow, because the position of the transducer head 124 must constantly be adjusted by the servo control system. Perturbations from the ideal track center negatively impact track to track spacing. Consequently, track to track spacing must be increased to compensate for this position error, leading to lower disk capacity. Further, positioning of the transducer head 124 is not as accurate on the written track 132 as it would be on an ideal track 216.

The perturbations in the written track 132 due to positioning errors can be effectively reduced by a self-servo writing process according to the present invention. In one embodiment, the present invention provides a method and system that allows self-servo writing servo information (e.g., servo bursts) in tracks 132 along with correction information that compensate for position errors (SSW_RRO). As such, after the SSW process, during disk operations and by using the correction information, a transducer head 124 servoing on a track 132 can more closely follow the path of an ideal track, such as the path of track 216.

As mentioned above, the tracks 132 on the disk 108 are each divided into a plurality of data fields 208 and servo sectors or hard sectors 212. The servo sectors 212 include, among other things, information for use by the disk drive 100 in locating a transducer head 124 above a desired track 132 of the disk 108. When a host computer requests that data be read from or written to a particular track 132 and data field 208 of the disk 108, the transducer head 124 must be moved to the track 132 and then must be positioned at a predetermined location relative to the centerline of the track 132 before data transfer can take place. For purposes of illustrating the present invention, it will be assumed that the transducer 124 should be placed on the track centerline in order to read from and write to the disk. It should be understood that the invention is not limited to solely reading and writing when the transducer is placed at the track centerline. As noted above, the track 132 is written to the disk 108 in a SSW process according to the present invention such that SSW_RRO is effectively reduced.

FIG. 3 illustrates typical servo hard sectors 130a, stored within the servo portion of a servo sector 212 for use in centering a transducer head 124 on a desired track 132. In this example, a servo hard sector 130a includes sets 130b

of staggered servo bursts 130c, designated as bursts A, B, C and D. The servo bursts 130c define the centerlines Tn-1, Tn and Tn+1 of the tracks 132 of the disk 108. In FIG. 3, the tracks 132 are diagrammatically laid out linearly in down track direction from left to right, and in cross track direction from top to bottom, of the page. Three example centerlines Tn-1, Tn and Tn+1 of three tracks 132 are defined by the servo bursts 130c on each track. The servo bursts 130c provide analog information to the servo system for transducer/head positioning. Other numbers of servo bursts and offset configurations are also possible. In the example herein, the A, B bursts form a burst pair and the C, D bursts form another burst pair. During normal disk drive operations, all of the four bursts A, B, C and D are used by the servo system when the transducer 124 is positioned at a write track centerline.

An example SSW process according to the present invention for writing a servo track 132 that is later sampled by the servo system in positioning the head 124 to follow a track which more closely resembles the ideal track 216, is now generally described. A temporary reference pattern of servo information (not shown) is initially provided on the disk 108 and is used by the servo system to determine a

position error signal (PES) for positioning the transducer 124 to write the servo bursts. In a preferred implementation of the SSW process, an iterative process such as described in the '362 patent is applied to the temporary reference pattern that is used for servoing while writing the final servo bursts A, B, C and D. This reduces the RRO that may have been written into the temporary servo pattern itself. The temporary servo pattern, with reduced RRO, is then used for writing the servo bursts.

The example SSW process described herein is in conjunction with a "trimmed" servo burst system. However, as those skilled in the art will appreciate, the present invention is useful with untrimmed, and other trimmed, servo burst systems. As used herein, a trimmed servo burst is one in which a radial edge of the burst is DC erased during a subsequent pass of the write element at a displaced radial position relative to the disk. A burst is trimmed to have e.g. a lower radial edge to be in alignment with the upper radial edge of an adjacent burst. It is possible to trim a previously written burst during a single pass of the transducer write head along a servo-writing path for writing another burst. A discussion of trimmed and untrimmed bursts

is provided in U.S. Patent No. 6,519,107 to Ehrlich, et al., incorporated herein by reference.

The SSW process includes the steps of self-writing servo bursts along a track via a transducer, calculating repeatable runout correction values based on instantaneous position error values when writing the servo bursts, and writing the correction values to corresponding fields 133 (RRO fields) on the track. As such, the centerline of a mis-positioned data track is effectively moved (repositioned) to a corrected track center location. After the SSW process is completed, during disk drive operation, initially upon seeking to a data track and reading a first set of servo bursts 130c, the servo system follows the original (uncorrected) track centerline until it reads the correction values from the corresponding RRO field 133, and thereafter moves the head 124 to the corrected track centerline location. Thereafter, the servo bursts 130c and the correction values in the corresponding RRO fields 133 are used by the servo system to continue following the corrected (effectively re-positioned) track centerline.

As such, in one example, in self-writing a track 132, the transducer 124 is positioned to write the bursts A ("A

bursts") along a circular path during a revolution of the disk 108. Then, in another revolution the bursts C ("C bursts") are written. Then, in another revolution the transducer 124 is moved to write the bursts B ("B bursts"), wherein the bursts B trim off bottom edges of the bursts A, thereby defining a first burst seam (transition) 130d. The positioning errors when writing the seams 130d, which are measured while the servo system is self-writing the B bursts, are stored in memory. Finally, in another revolution, the bursts D ("D bursts") are written, wherein the bursts D trim off bottom edges of the bursts C, thereby defining a second burst seam (transition) 130e. The positioning errors when writing the seams 130e, which are measured while the servo system is self-writing the D bursts, are also stored in memory. Then, for example, the first and second positioning errors are used to generate correction values that are written to RRO fields 133 corresponding to the four servo bursts A, B, C and D of track Tn-1 in FIG. 3.

Other sequences for writing and trimming the bursts 130c are possible. The motion of the head 124 defines where the seams 130d and 130e occur. As there is head motion due to disturbances that cause non-repeatable runout disturbances (NRO), the difference between the intended position of the

seams 130d, 130e and the actual position of the seams 130d, 130e, due to such head movement, is a capture of the NRO, and is recorded in the burst pair patterns by mis-positioning of the seams 130d and 130e (SSW_RRO). According to the example described herein, to compensate for the SSW_RRO in the seams 130d and 130e, correction values are determined and written to RRO fields 133 as described, to compensate for the mis-positioning of the seams 130d and 130e. For example, if the seam 130e (and/or seam 130d) is too far off towards the outer diameter (OD) of the disk 108 by a certain amount (offset from ideal), then the correction values are calculated and written into the corresponding RRO fields 133 during the SSW process, such that after the SSW process, during disk drive operation, the servo system uses the seam positions 130e, 130d and the correction values in the corresponding RRO fields 133, to position the transducer 124 towards the inner diameter (ID) by said certain amount, such that the servo system effectively follows a track centerline at the intended (e.g., ideal/circular) track position.

Specifically, after the final servo bursts 130c are written by the SSW, in normal disk drive operations, the servo system senses the position of the seams 130d between the bursts A and B, and the seams 130e between the bursts C

and D, for track following. At each read/write position, one seam 130d and one seam 130e is used, wherein the servo system averages the observed position of the seams 130d, 130e, and combines that average with the correction information in the corresponding RRO field 133, to generate a position error signal (PES) to control the VCM 128 for properly positioning the transducer 124 over the tracks 132. Therefore, if during the SSW process, one or both of the seams 130d, 130e were mis-positioned slightly towards e.g. the ID of intended (ideal) position, then according to the present invention, the effect of the correction value in the PES is to compensate for that mis-positioning, whereby the transducer head 124 is made to follow the path of an ideal track 216 using said PES generated in each of the servo sectors 212 of a particular track 132.

The SSW_RRO in each of the seams 130d, 130e is related to the instantaneous PES at the time the seams 130d, 130e are written (created). The instantaneous PES is determined using said pre-existing temporary servo information that is used for head positioning during the SSW process. As noted, an iterative process such as described in the '362 patent is applied to the temporary servo information to reduce the RRO that may have been written into the temporary servo

information itself. The temporary servo information, with reduced RRO, is then used for writing the servo bursts.

In one example, the temporary servo information includes a set of circumferentially spaced spiral tracks (each spiral staring from a position on the disk OD and ending on a position on the disk ID), the spirals have information written along their length that provide radial positions for track following in self-writing the servo bursts A, B, C and D on circular tracks.

In one case, each servo burst is written a short time after a spiral. Because the NRO is at a lower frequency than the spiral sample rate, the head cannot move too far off a circular track after each spiral. As such, the instantaneous PES value at the time the head passed over the last spiral is a good estimate of the position error when that servo burst was written. It is preferable, to record (e.g., store in memory) the instantaneous PES signal at the time that the transducer crosses the spiral, immediately prior to writing the servo bursts in a hard sector. In the example herein, where four servo bursts are used, the instantaneous PES values, when the servo bursts were written in servo sectors around a track, are used to back-calculate the correction

values to be written in the RRO fields on the track. In one version, the calculated correction values are written to corresponding RRO fields around the track in a disk revolution after the servo bursts are written.

If the spiral has been corrected for RRO by a process such as the process described in the '362 patent, then the PES signal is equal to the mis-position of the transducer from the ideal track center (the frequency content of the NRO is significantly lower than the servo sample rate). This measured instantaneous PES signal is a good indication of the mis-position of the transducer as the servo bursts are written. It is also possible to record the instantaneous PES signal on spirals on both sides of the servo bursts and to extrapolate a more accurate mis-position of the servo bursts as they are written in the SSW process. When the servo bursts 130c have been written, the induced error due to servo burst mis-positioning is determined, and correction values calculated. Once the correction value (e.g., position error) has been calculated, it can be written to the RRO fields 133 of the servo system of the drive. In this example, where multiple servo bursts are used, it will be necessary to reposition the head to the write center prior to writing the correction in the RRO field 133.

An example implementation of the above SSW process is now described in more detail. In a preferred implementation of the SSW process, a process such as described in the '362 patent is applied to the temporary servo information (e.g., spiral tracks) that are used for servoing while writing the final servo bursts A, B, C and D. This reduces, and can virtually eliminate, the RRO that may have been written into the temporary servo information itself. The temporary servo information with reduced RRO, is then used for writing the servo bursts A, B, C and D. However, as mentioned, in writing the servo bursts 130c that define the seams 130d, 130e, NRO is recorded as SSW_RRO as mis-positioned seams 130d and/or 130e that perturb the track 132. The instantaneous PES from the temporary servo information when laying down the seams 130d, 130e indicates how far the seams 130d, 130e are mis-positioned from their ideal/intended position. The instantaneous PES (PES_RRO) is obtained from the temporary servo information, the instant one servo burst trims another servo burst, and are stored in memory.

As such, the instantaneous PES (PES_RRO) while performing a burst write/trim operation that controls a seam position, indicates how far the seams 130d, 130e were mis-positioned. That is, the mis-positioning error SSW_RRO is

the stimulus and PES_RRO is the response (the mis-positioning error (SSW_RRO) can be calculated from the position error values (PES_RRO), such as described in the '362 patent).

The correction values are calculated based on the PES_RRO, as described further below, to compensate for mis-positioning of the seams 130d, 103e. The correction values are written to the RRO fields 133 during the SSW process, and after the SSW process is completed, during disk drive operations, the correction values are read from the RRO fields 133 and combined with the corresponding servo burst 130c position information, to generate a control signal (PES) for the VCM 128 to position the transducer 124 to compensate mis-positioning the seams 130d, 103e, thereby reducing the overall track runout.

In general, the instantaneous position error due to repeatable runout (PES_RRO) is derived by reading the temporary servo information when the seams are laid down for a track 132, and then generating a position error signal therefrom. The process of obtaining position error signal/data from the temporary servo information is known by those skilled in the art, and as such not described herein. Preferably, the position error data is obtained from the

temporary servo information, wherein the RRO that may have been recorded in the temporary servo information is reduced by known methods.

FIG. 4 shows a detailed flowchart of the steps of self-servo writing (SSW) process according to the present invention. Further, FIG. 5A shows a diagrammatic representation of an example self-servo writing (SSW) process (such as shown in FIG. 4) according to the present invention. Four tracks, designated as tracks N, N+1, N+2 and N+3, are shown, wherein the track centerlines are defined by servo bursts A, B, C, D in each servo wedge. Track N+1 is shown with SSW positioning error, such that the track centerline is at the incorrect location 150A (i.e., the seams 103d, 103e in track N+1 cause centerline of the track to be offset from its intended location). According to the present invention, the location of the centerline for track N+1 is effectively moved to the correct location 150B, based on correction information in a corresponding RRO field created as described below in conjunction with FIG. 5B.

FIG. 5B shows a diagrammatic representation of an example self-servo writing (SSW) process (such as shown in FIG. 4) according to the present invention. FIG. 5B shows

tracks N, N+1, N+2 and N+3 at corrected centerline positions. The 'inconsequential bursts' serve to isolate adjacent tracks and prevent any correction accumulation.

The servo bursts A, B, C and D define the tracks N, N+1, N+2 and N+3 as shown, and correspond to different track "modes" (e.g., TM1, TM3, TM5 and TM7). Each track mode indicates the sequence in which the bursts are written/trimmed, and the corresponding PES is based on combinations of the burst difference values corresponding to the track mode. For example, track mode TM1 corresponds to the burst combination PES= -(A-B)+(C-D), the track mode TM3 corresponds to the burst combination PES=(A-B)+(C-D), the track mode TM5 corresponds to the burst combination PES=(A-B)-(C-D), and the track mode TM7 corresponds to the burst combination PES=-(A-B)-(C-D). Other track modes TM0, TM2, TM4, TM6 are used for two burst tracks (i.e., A and B bursts or C and D bursts).

In this example, in writing the servo bursts for track N using track mode TM7, first, all the A bursts are written in a revolution. Then, in another revolution all the C bursts for the track N are written. Then, in another revolution the B bursts are written wherein each B burst trims the bottom

edge of a corresponding A burst (represented as a dashed box, designated "*A trimmed*"). As each A burst is trimmed, the instantaneous PES (PES_RRO) at that location is stored in memory, wherein the instantaneous PES information indicates the position of the A,B seam 130d. Then, in another revolution the D bursts are written wherein each D burst trims a corresponding C burst (represented as a dashed box, designated "*C trimmed*"). As each C burst is trimmed, the instantaneous PES (PES_RRO) at that location is stored in memory, wherein the instantaneous PES information indicates the position of the C,D seam 130e. The recorded PES_RRO values are then used to determine correction/offset values that are written into the RRO fields.

Referring back the steps in the flowchart in FIG. 4 for self-servo writing burst patterns that are shown by the diagrammatic representation in FIG. 5B, the steps in FIG. 4 refer to writing/trimming servo bursts from bottom to top, in sequence, in FIG. 5B. In this example, writing the 4-burst pattern is performed in eight steps which represent the four different track modes. The process starts at a track mode (e.g., TM1), and cycles through the track modes depending on the steps in the eight-step process, as shown by the example in FIG. 5B and described hereinbelow.

To simplify understanding, the steps in FIG. 4 are also shown FIG. 5B, from bottom to top of FIG. 5B, in sequence, and each step is aligned with the respective burst writing/trimming operation. Referring to the steps in FIG. 4 in conjunction with the diagram in FIG. 5B (starting from track N+3 at the bottom of FIG. 5B, and moving from the bottom to the top of FIG. 5B), the detailed steps for writing the servo bursts for the four tracks N, N+1, N+2 and N+3 are described, wherein:

1) The B bursts are written in a disk revolution (step 400);

2) Then D bursts are written in another disk revolution (step 402);

3) Then A bursts are written in another disk revolution, wherein each A burst trims a corresponding B bursts (inconsequential burst) (step 404);

4) Then C bursts are written in another disk revolution, such that each C burst trims a corresponding D burst (creating C,D seams 130e), wherein the instantaneous PES (PESc) is recorded (e.g., stored in memory in the controller 136) while writing each C burst (step 406);

5) Then B bursts are written in another disk revolution such that each B burst trims a corresponding A burst (creating A,B seams 130d), wherein the instantaneous

PES (PESb) is stored in memory while writing each B burst (step 408);

6) Then, the just stored PES values (PESb and PESc) are used to determine a correction value ERC, and the correction value is written to the corresponding RRO field (step 410);

7) Then D bursts are written in another disk revolution such that each D burst trims a C burst (inconsequential burst) (step 412);

8) Then A bursts are written in another disk revolution such that each A burst trims a B burst (creating A,B seams 130d), wherein the instantaneous PES (PESa) is stored in memory while writing each A burst (step 414);

9) Then C bursts are written in another disk revolution such that each C burst trims a corresponding D burst (creating C,D seams 130e), wherein the instantaneous PES (PESc) is stored in memory while writing each C burst (step 416);

10) Then, the just stored PES values (PESa and PESc) are used to determine a correction value ERC, and the correction value is written to the corresponding RRO field (step 418);

11) Then B bursts are written in another disk revolution such that each B burst trims an A burst (inconsequential burst) (step 420);

12) Then D bursts are written in another disk revolution such that each D burst trims a corresponding C burst (creating C,D seams 130e), wherein the instantaneous PES (PESd) is stored in memory while writing each D burst (step 422);

13) Then A bursts are written in another disk revolution such that each A burst trims a corresponding B burst (creating A,B seams 130d), wherein the instantaneous PES (PESa) is stored in memory while writing each A burst (step 424);

14) Then, the just stored PES values (PESa and PESd) are used to determine a correction value ERC, and the correction value is written to the corresponding RRO field (step 426);

15) Then C bursts are written in another disk revolution such that each C burst trims a D burst (inconsequential burst) (step 428);

16) Then B bursts are written in another disk revolution such that each B burst trims a corresponding A burst (creating A,B seams 130d), wherein the instantaneous

PES (PESb) is stored in memory while writing each B burst (step 430);

17) Then D bursts are written in another disk revolution such that each D burst trims a corresponding C burst (creating C,D seams 130e), wherein the instantaneous PES (PESd) is stored in memory while writing each D burst (step 432);

18) Then, the just stored PES values (PESb and PESd) are used to determine a correction value ERC, and the correction value is written to the corresponding RRO field (step 434); and so on.

The calculation of the correction values ERC, is dependent of the servo write technique being used. For example, if in the example of FIGS. 4, 5A and 5B, a one-pass trimmed process is used to write the servo bursts, the ERC calculation is track mode dependent according to Table 1 below, wherein x is a positive integer:

Table 1

Trk mode	data trk no.	servo trk no.	PES	ERC
5	4 * x + 0	3*x + 0	(A-B)-(C-D)	-(PESa + PESd)/2
3	4 * x + 1	3*x + 1	(A-B)+(C-D)	-(PESa + PESc)/2
1	4 * x + 2	3*x + 2	-(A-B)+(C-D)	-(PESb + PESc)/2
7	4 * x + 3	3*x + 2	-(A-B)-(C-D)	-(PESb + PESd)/2

In another example, if an untrimmed one pass process is used to write the servo bursts, the ERC calculation is ERC = -(PESa +PESb +PESc +PESd)/4, independent of track mode. As those skilled in the art will recognize, similar calculations can be used for processes with multiple writes and independent trims.

As those skilled in the art will appreciate with the benefit of reading this disclosure, implicit in the above steps is that the transducer 124 is moved under PES and timing control to write the various bursts at different radial locations. Further, the transducer 124 is moved to write the RRO fields. In one implementation, the transducer is controlled to "back up" one and a half servo steps to write the RRO field that corresponds to the write center position. In another implementation, if backing-up to write the RRO fields causes problems by interrupting the servo write process, then the RRO fields are written to a convenient track location as soon as the ERC values are calculated (without backing-up the head 124), and then in a later step (e.g., in a test process) the RRO fields are "moved" by reading the correction information therein and re-writing the correction information at the desired track location. In accordance with another aspect of the present

invention, if the micro-jog (reader to writer offset) profile for the head is determined, then the RRO correction for the read position can also be calculated.

As those skilled in the art appreciate, the present invention is applicable to other burst patterns and other burst numbers (e.g., 6 burst system) by taking into account the burst relationships and how the bursts trim one another. The present invention is also applicable to systems where there are independent trim passes (e.g., the burst trim passes are separate from the burst write passes). The present invention is also applicable to servo writing methods that use multiple writes, wherein e.g. the A burst is written and trimmed twice, such that the average of the A bursts and B bursts are used. That mis-positioning of each servo burst is the sum of the instantaneous PES due to recorded NRO and whatever correction performed when correcting the spirals for RRO therein. This indicates the mis-positioning of each burst, which is used to calculate the correction values. In one example, the correction values are held in memory until they are written to disk into the RRO fields. Typically, one or more revolutions of correction values are held in memory (e.g., for the current track) until written to disk in the RRO fields 133 during the SSW process. Depending on how

correction value is used (i.e., added to, or subtracted from, the PES) by the servo system during normal operation, the correction value can have a negative or positive value. In this example, the correction values are effectively subtracted from PES.

After the SSW process, during normal operation of the disk drive 100, the transducer head 124 reads the servo bursts in each servo sector 212 of a desired track 132. If the head 124 is placed at the seam 130d between bursts A and B, the head readback signal includes half the signal value of burst A and half the signal value of burst B. If the head 124 is shifted off towards burst A, magnitude of burst A increases and magnitude of burst B decreases. The same applies to burst pair C, D. The A,B and C,D bursts are shifted in position from each other by fractions of track width, such as e.g. 1/3 of track width in this example. For head positioning, in one example, the signal value from the flux transitions in the servo bursts induced to the transducer are used in a decoding process by demodulating the induced transducer signals to form difference values (difference signals) including A-B, and C-D phases. Transducer position tracking information is decoded by using combinations of the A-B burst phase difference and the C-D

burst phase difference depending on radial (cross track) location of the transducer relative to track centerline. Further, the correction values from the corresponding RRO field is read via the transducer 124, and combined with the burst phase difference signals, to obtain said position error signal (PES) for transducer positioning by the servo system. An example of using ERC values in combination with burst phase values, for servoing during normal disk drive operations, is described in the '362 patent.

The PES indicates the distance between the center of the transducer head 124 and the centerline (e.g., centerline 320b) of the desired track. For a requested read/write operation, the PES signal is used by the disk drive 100 to change the position of the transducer head 124 to one that is closer to the desired (centered) position. This centering process is repeated for each successive sector on the track until the requested read/write operation has been performed in the appropriate data field 208 of the disk 108. It should be appreciated that other schemes for storing servo information on the magnetic media, such as schemes having said A, B position bursts; using zones; constant linear density (CLD) recording, split data fields; and/or hybrid

servo, can also be used in accordance with the present invention.

The present invention can be applied to any self-servo writing system where some temporary servo information is used for timing and transducer positioning to write final servo data patterns. This may include printed media, partial write systems and self-propagation servo write systems, and can be applied to systems using multi pass writes and trims, as those skilled in the art can appreciate. Because the temporary servo information will inherently have a certain amount of RRO in it, it is necessary to remove the RRO with some type of real-time runout correction system, to circularize the temporary servo information before using it to write the final servo bursts. The correction being used to cancel out the NRO is added to whatever correction is needed to circularize the temporary servo information.

As known to those skilled in the art, in addition to the logic blocks shown in the drawings, the various methods and architectures described herein can be implemented as: computer instructions for execution by a microprocessor, as ASIC units, firmware, as logic circuits, etc.

The present invention has been described in considerable detail with reference to certain preferred versions thereof; however, other versions are possible. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.